

# Weakly broadened iron line in the X-ray spectrum of the Ultra Luminous X-ray source M82 X-1

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## ABSTRACT

In this paper we present the best quality *XMM-Newton* and *Suzaku* data from M82 X-1 so far. We analyze the spectra of this remarkable Ultra-Luminous X-ray Source in a self-consistent manner. We have disentangled emission from the host galaxy, responsible for the soft X-ray emission ( $E \leq 2.5$  keV), which is successfully described by a two-temperature thermal emission from a hot plasma in multi-phase state, plus a narrow Fe line emission at 6.7 keV. This allowed us to properly study the intrinsic continuum emission from M82 X-1. The continuum of the *Suzaku* spectrum is curved and the high quality data of the *Suzaku* spectrum allowed us to significantly detect a weakly broadened Fe  $K\alpha$  emission line. The Equivalent-Width is in the range 30–80 eV and it does not depend on the model applied for the continuum. Assuming that this line is coming from the ULX via disc fluorescence, the data indicates a disc truncation at a radius of 6–20 gravitational radii. This value is comparable to or even larger than the Innermost Stable Circular Orbit of a non-spinning (Schwarzschild) black hole. Future longer observations might test this scenario.

**Key words:** line: formation – black hole physics – X-rays: galaxies – X-rays: general

## 1 INTRODUCTION

Ultra-luminous X-ray (ULX) sources are point like, off-nuclear extra Galactic sources with observed luminosities greater than the Eddington limit for a  $10 M_{\odot}$  black hole (BH), with  $L_X \geq 10^{39}$  erg s<sup>-1</sup> (Fabbiano 1989). The true nature of these objects is still open to debate (Miller & Colbert 2004). One fundamental issue is whether the emission is isotropic or beamed along our line-of-sight. A possible scenario for geometrical beaming involves super-Eddington accretion during phases of thermal-timescale mass transfer (King 2002). Alternatively, if the emission is isotropic and the Eddington limit is not violated, ULX must be fuelled by accretion onto Intermediate-Mass BH (IMBH), with masses in the range 100–10 000  $M_{\odot}$  (Colbert & Mushotzky 1999). Of course, it is possible that some ULX appear very luminous due to a combination of moderately high mass, mild beaming and mild super-Eddington emission. It is also possible that ULX are an inhomogeneous population, comprised of both a subsample of IMBH and moderately beamed stellar mass black holes (Fabbiano & White 2006; Miller & Colbert 2004).

M82 X-1 (also named CXOU J095550.2+694047) is one of the brightest ULX in the sky. The host galaxy is located nearby, at a distance of 3.6 Mpc (Freedman et al. 1994), making M82 X-1, with an average X-ray luminosity  $\geq 10^{40}$  erg s<sup>-1</sup>, an excellent target for the detailed modelling of the X-ray spectrum in

such objects. M82 X-1 is one of the few ULX for which (10–200 mHz) Quasi-Periodic Oscillations (QPO) have been found (Strohmayer & Mushotzky 2003) and is the prototype ULX with curved X-ray spectra. Miyawaki et al. (2009) analyzed the *Suzaku* spectrum of this source (with an energy coverage extending up to 20 keV) and tested the data to a variety of models, confirming that this source has a spectrum curved at high-energies. Mucciarelli et al. (2006) analyzed the longest *XMM-Newton* observations available in the archive and applied models of diffuse thermal emission from the galaxy to understand the high-energy curvature of the spectrum. The authors found that the high energy curvature could indeed be explained by the presence of a third thermal component having very high column densities ( $N_H \approx 10^{23}$  cm<sup>-2</sup>). This contradicts recent *CHANDRA* observations by Feng & Kaaret (2010), who found column densities of  $N_H \approx 1 \times 10^{22}$  cm<sup>-2</sup>, in fitting the X-ray spectra at the position of this ULX.

As in the case of black hole binaries (BHBs), some ULXs undergo spectral transitions from a power-law dominated state to a “high-soft” state (see e.g. McClintock & Remillard for a description of the spectral states in BHBs). During the power-law state the high-energy spectra of ULXs is inferred to have a power-law spectral shape in the 3–8 keV spectral range, together with a high-energy turn-over, and a soft-excess (e.g. Kaaret et al. 2006). This soft-energy excess can be modelled by emission coming from the inner-accretion disc and is characterized by a low disc temperature of  $\approx 0.2$  keV (Miller et al. 2003, 2004). If these observed characteristics are entirely due to a BH accreting at sub-Eddington rates,

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they imply the presence of an IMBH with  $M \approx 100 - 1000 M_{\odot}$ . In the case of M82 X-1, due to the huge absorption at soft X-rays by the host galaxy, this soft X-ray excess is not observed in the spectra. Systematic studies of the highest quality XMM-Newton ULX spectra by Yoshida et al. (2010) and Stobbart et al. (2006) have shown that the majority of ULXs display a break/turnover at high energies ( $\geq 3$  keV). Such breaks are not commonly seen in the spectra of BHBs. Gladstone et al. (2009) argue that this turnover could be due to Comptonization from an optically thick corona, which would shroud the inner regions of the accretion disc and artificially lower the inner temperatures obtained from simple spectral modelling. Under such interpretation most ULXs would then represent a new accretion state for stellar-mass BHBs. An alternative explanation is proposed by Caballero-García & Fabian (2010), where the authors note that in many cases the turnover occurs between 5–7 keV, and could be due to a combination of the Iron  $K_{\alpha}$  emission line and absorption edge (6.4 and 7.1 keV respectively for neutral Iron) in a relativistically blurred reflection spectrum from the inner accretion disc of a spinning black hole. Here reflection refers to the back-scattering and fluorescence of X-rays (George & Fabian 1991). Under this interpretation, the soft excess emission often assumed to come directly from the accretion disc is also due to blurred reflection, meaning that the disc emission is not directly observed. Other explanations have also been proposed, often based on emission from the aforementioned slim discs in which advection of radiation from the inner regions of the accretion disc reduces the observed luminosity (Abramowicz et al. 1988). In the case of M82 X-1, the huge intrinsic column density of the galaxy ( $N_H \approx 10^{22} \text{ cm}^{-2}$ ), makes the detection of soft X-ray spectral features from this source very unlikely.

Here we use the best publicly available data from *Suzaku* and *XMM-Newton*, currently being the best available X-ray data from this source. Our goal is to disentangle both the emission from the host galaxy and the intrinsic spectrum from the source (Section 3) and to analyze the latter with current models used for the description of the spectra from ULXs (Section 4). We notice the presence of a broad Fe K line in the residuals and explore its significance in Section 5. Eventually, physical implications are discussed in Section 6.

## 2 OBSERVATIONS AND DATA REDUCTION

### 2.1 XMM-Newton

In this work, we consider the longest publicly available *XMM-Newton* EPIC-pn spectra from M82 X-1 (Obs. IDs: 0112290201 and 0206080101). The source was very bright, with a count rate of  $3.06 \pm 0.012$ ,  $2.341 \pm 0.007 \text{ cts/s}$ . The datasets were obtained through the *XMM-Newton* public data archive. The EPIC-pn camera has a higher effective area than the EPIC-MOS cameras, and drives the results of any joint spectral analysis. The reduction and analysis reported in this work used SAS version 9.0.0. We checked for pile-up in all the observations and found that this was not significant (i.e. it is  $\leq 5\%$  for the high energy channels) for both observations.

In Table 1 we present a log of the observations. We applied the standard time and flare filtering (rejecting high-background periods of rate  $\geq 0.4 \text{ counts/s}$ , as recommended for the pn camera<sup>1</sup>).

We filtered the event files, selecting only the best-calibrated events (pattern  $\leq 4$  for the pn), and rejecting flagged events (flag = 0).

For each exposure, we extracted the flux from a circular region on the source (centre at coordinates RA =  $9^{\text{h}}55^{\text{m}}50.2^{\text{s}}$  deg, Dec =  $69^{\circ}44'04.7''$  deg and radius 18 arcsec). The background was extracted from a circular region, not far from the source and away from boundaries of the chips and the nucleus of the galaxy. We built response functions with the SAS tasks *rmfgen* and *arfgen*. We fitted the background-subtracted spectra with standard models in XSPEC 12.5.0 (Arnaud 1996). All errors quoted in this work are 90% confidence errors. For the spectral fitting we used the 0.5–10 keV range. The resulting spectra were grouped with the FTOOL *grppha* to bins with a minimum of 20 counts each.

### 2.2 Suzaku

M82 X-1 was observed with *SUZAKU* (Mitsuda et al. 2007) on three occasions in 2005 October 4, 19 and 27 for approximately 32, 40 and 28 ks respectively. The four operating detectors constituting the X-ray Imaging Spectrometer (XIS; Koyama et al. 2007) were operated in the “normal” clock mode in all observations. In all cases, the detectors were operated in both the 3x3 and 5x5 editing modes. A total (co-added) front-illuminated (FI) exposure of approximately 96, 110 and 80 ks were obtained for the three respective observations. The corresponding back-illuminated (BI) exposures were approximately 32, 37 and 27 ks. Using the latest HEASOFT software package we processed the unfiltered event files for each of the XIS CCDs and editing modes operational in the respective observations, following the *SUZAKU* Data Reduction Guide<sup>2</sup>. We started by creating new cleaned event files by re-running the *SUZAKU* pipeline with the latest calibration, as well as the associated screening criteria files. XSELECT was used to extract spectral products from these event files. In all observations, source events were extracted from a circular region of 180” radius centred on the point source, and background spectra from another region of the same size, devoid of any obvious contaminating emission, elsewhere on the same chip. The script “xisresp”<sup>3</sup> with the “medium” input was used to obtain individual ancillary response files (arfs) and redistribution matrix files (rmfs). “xisresp” calls the tools “xisrmfgen” and “xissimarfgen”. Finally, we combined the spectra and response files from the three front-illuminated instruments (XIS0, 2 and XIS3) using the FTOOL *ADDASCASPEC*. This procedure was repeated for each observation resulting in a total of six XIS spectra. After inspecting that there were no significant spectral differences between the three observations we further co-added the various front and back-illuminated spectra. This resulted in a total good exposure of approximately 280 and 92 ks for the front and back-illuminated spectrum respectively. Finally, the FTOOL *GRPPHA* was used to give at least 20 counts per spectral bin. The two XIS spectra was fit in the 1.5–10.0 keV energy range with the 1.7–2.1 keV energy range being ignored due to the possible presence of un-modeled instrumental features.

For the hard X-ray detector (HXD, Takahashi et al. 2007) we again reprocessed the unfiltered event files for the respective observations following the data reduction guide (only the PIN data is used in this analyses). Since the HXD is a collimating rather than an imaging instrument, estimating the background requires individual consideration of the non X-ray instrumental background (NXB)

<sup>1</sup> Information provided at “node52.html” of the User Scientific Guide.

<sup>2</sup> <http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/>

<sup>3</sup> <http://suzaku.gsfc.nasa.gov/docs/suzaku/analysis/xisresp>

**Table 1.** *XMM-Newton* and *Suzaku* observations log.

Satellite	Obs	Obs ID	Date	Exposure time (s)
XMM-Newton	1	0112290201	2001-05-06	30 558
XMM-Newton	2	0206080101	2004-04-21	104 353
<i>Suzaku</i>	3	100033010	2005-10-04	32 327
<i>Suzaku</i>	3	100033020	2005-10-19	40 358
<i>Suzaku</i>	3	100033030	2005-10-27	28 363

and cosmic X-ray background (CXB). The appropriate response and NXB files were downloaded for the respective observations<sup>4</sup>; in each case the tuned (Model D) background was used. Common good time intervals were obtained with MGTIME which combines the good times of the event and background files, and XSELECT was used to extract spectral products. Dead time corrections were applied with HXDDTCOR, and the exposures of the NXB spectra were increased by a factor of ten, as instructed by the data reduction guide. The contribution from the CXB was simulated using the form of Boldt (1987), with the appropriate normalisation for the nominal pointing (all observations were performed with HXD nominal pointing), resulting in a CXB rate of  $\approx 2.97 \times 10^{-2}$  count s<sup>-1</sup>. The NXB and CXB spectra were then combined using MATHPHA to give a total background spectrum, to which a 2% systematic uncertainty was added. Similarly to the XIS data, we co-added all three PIN observations and grouped the final spectrum to have a minimum of 500 counts per energy bin to improve statistics, and again allow the use of  $\chi^2$  minimization during spectral fitting. The PIN data reduction yielded a total (co-added) source rate of  $(1.5 \pm 0.3) \times 10^{-2}$  count s<sup>-1</sup> which is 2.5% of the total observed flux, with a good exposure time of  $\approx 93$  ks.

### 3 THE DETERMINATION OF THE EMISSION FROM THE DIFFUSE COMPONENT

The soft energies in the spectra of M82 X-1 are dominated by the presence of X-ray emission lines having constant energies and width, thus indicating an origin in the diffuse gas of the galaxy, rather than intrinsic to M82 X-1. We performed simultaneous fits of all the observations, considering constant properties (in time) for both thermal components of the diffuse emission from the galaxy (i.e. temperatures and element abundances tied between the observations, although see below for the latter). This is as expected, since the physical properties of the galaxy are likely to be constant with time. To account for these lines we initially applied a single thermal plasma model with variable metal abundances (vmekal model in XSPEC) to describe the softest part of the spectrum ( $\leq 2.5$  keV). However, strong residuals were left with this model and we thus added a further second thermal component (as previously done in Mucciarelli et al. 2006) resulting in a significant improvement to the fit, with the residuals at  $\leq 2.5$  keV being almost null, within the instrumental errors. The values obtained for the spectral parameters are shown in Table 2. The value for the temperature of the hottest component in Obs. 2 found by Mucciarelli et al. (2006) ( $kT = 1.67 \pm 0.11$  keV), is different possibly due to the addition of a further thermal disc component in their analyses. We tested for the presence of this further component and did not find it to be significant in the spectra.

**Table 2.** Best-fit model spectral parameters with 90% confidence errors obtained for the Global-Simultaneous fit shown in Figure 1.

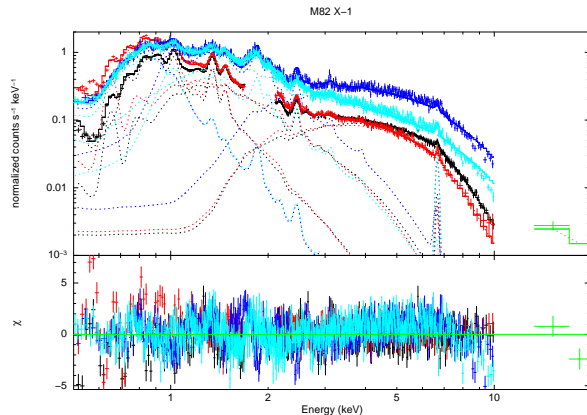
Models	Parameters	Obs 1	Obs 2	Obs 3
Diffuse	$N_H(1)$	$1.42 \pm 0.03$	$1.25 \pm 0.03$	$0.58 \pm 0.01$
Plasma	$(10^{22} \text{ cm}^{-2})$			
	$kT(1)$ (keV)	= Obs3	= Obs3	$0.96 \pm 0.02$
	$N_H(2)$	$0.13 \pm 0.02$	$0.18 \pm 0.02$	$0.06 \pm 0.02$
	$(10^{22} \text{ cm}^{-2})$			
	$kT(2)$ (keV)	= Obs3	= Obs3	$0.60 \pm 0.02$
Narrow Fe	$E_l$ (keV)	= Obs3	= Obs3	$6.7 \pm 0.3$
Line	$\sigma$ (keV)	= Obs3	= Obs3	$0.06 \pm 0.04$
Highecut	$\Gamma$	$1.47 \pm 0.03$	$1.49 \pm 0.03$	$1.79 \pm 0.02$
Powerlaw	$E_c$ (keV)	–	–	$6.83 \pm 0.19$
	$E_f$ (keV)	–	–	$9.7 \pm 1.4$

We fixed metal abundances to solar values for Obs. 1 and 2 (*XMM-Newton* spectra), in agreement with previous work on *XMM/RGS* data (Read & Stevens 2002). Setting solar metal abundances for Obs. 3 (*Suzaku* spectrum) provided a very poor fit ( $\chi^2/\nu = 1.92$ ,  $\nu = 3450$ ) and visible low energy residuals. The best fit was achieved allowing metal abundances free to vary in the *Suzaku* spectra and they turned out to be super-solar for certain elements ( $Z = 6 - 8 \times Z_\odot$  for Si, S and Fe). This fit apparently indicates super-solar abundances for the diffuse emission and therefore it is hard to reconcile with previous studies of metallicity of this galaxy (Origlia et al. 2004; Ranalli et al. 2008). These lines might have a different origin apart from the emission from the relatively *cold* emission from the galaxy (nevertheless, we refer to this emission as *hot* hereafter), which the model can not account for. Further studies of these emission lines require the use of additional emission processes/components that we will not consider in the present paper.

There is also a narrow line (i.e.  $\sigma = 0$ ) centred at  $\approx 6.7$  keV coincident in energy with Fe He $_{\alpha}$ . We included it in all the fits reported above and in the following fits as well. This line can not be accounted for the two thermal models (with solar abundances) employed to model the soft X-ray emission. We extracted spectra from other regions of the galaxy and confirm the presence of the narrow line. Strickland & Heckman (2007) spectrally resolved the Fe line at 6.7 keV with *Chandra* and *XMM-Newton* data and showed that it is primarily distributed diffusely rather than associated with discrete sources.

Having confirmed that the combination of two thermal plasma components plus emission from a narrow Fe line indeed provides a first approximation description of the emission from the diffuse component in the global-simultaneous fits, we proceed with this combination in all fits presented hereafter. As previously noticed by Miyawaki et al. (2009) for Obs. 3 (for which the energy coverage is maximum 0.5 – 20 keV in contrast to 0.5 – 10 keV for the remainder observations), the high-energy spectrum is strongly curved. We applied a curved phenomenological model to describe the high-energy spectrum (high-energy cut-off in XSPEC). From the global simultaneous fits, the cut-off for Obs. 3 was constrained to be  $E_c = 6.83 \pm 0.19$  keV. Mizuno et al. (2007) reported a very similar cut-off at 6–7 keV in the spectrum of NGC 1313 X–1. The results of the global-simultaneous fits are shown in Figure 1 and Table 2.

<sup>4</sup> <http://www.astro.isas.ac.jp/suzaku/analysis/hxd/>



**Figure 1.** Global-Simultaneous fit of spectra of Obs. 1, 2 and 3 with a continuum phenomenological model (Highecut Powerlaw for the high-energy emission). Diffuse emission from two hot plasmas ( $kT = 0.6$  keV and  $kT = 0.96$  keV) and solar metallicities for *XMM-Newton* spectra and emission from a narrow Fe line have been taken into account. Black, red, blue and green correspond to FI,BI *Suzaku*/XIS, *XMM-Newton* and *Suzaku*/PIN/HXD spectra, respectively.

#### 4 THE DETERMINATION OF THE BEST MODEL FOR THE CONTINUUM INTRINSIC TO THE SOURCE

Considering the results obtained in the previous Section regarding the X-ray emission from the diffuse emission of the galaxy, we are now in good condition to determine the best model for the intrinsic emission of the source. We can see in Figure 1 and in the power-law photon indices obtained (see Table 2) that the intrinsic spectrum of M82 X-1 is variable. Thus we fitted each spectrum separately and we froze the parameters regarding the emission from the diffuse component from the model of the previous Section (i.e. 2 mekal components plus narrow Fe line), expected to be constant. To this base-line model we added further models to describe the high-energy emission, as explained in the following.

The high-energy spectra are strongly curved, and we find that a model consisting by an absorbed power-law is not a good description of the data of Obs. 3 ( $\chi^2/\nu = 1.25, 1.28, 2.16$  with  $\nu = 1340, 1399, 730$  for Obs. 1, 2 and 3, respectively). The results from the *Suzaku* spectrum are in agreement with the analysis from Miyawaki et al. (2009). We considered X-ray emission from a multicolor disc (diskbb in XSPEC) and Comptonization (CompTT in XPSEC).

The spectra of M82 X-1 are convex, representing very well the prototype of ULXs of this class (Makishima 2007). Indeed, the spectra are well fitted with emission from a rather hot inner disc ( $kT_{\text{in}} = 2.7 - 3.6$  keV; see Table 3), values in agreement with previous studies (Strohmayer & Mushotzky 2003; Miyawaki et al. 2009). Nevertheless, these values are significantly hotter than those obtained in recent observation ( $kT_{\text{in}} = 0.9 - 1.6$ ) of M82 X-1 by Feng & Kaaret (2010). This fact might correspond to the known positive temperature-luminosity correlation known to act in ULXs (Makishima et al. 2000). But we do not observe a true change in the luminosities of M82 X-1 with respect those from Feng & Kaaret (2010), being very similar to the ones reported in this paper. Feng & Kaaret (2010) identify their spectra as being from M82 X-1 in a state similar to the canonical high-soft state in BHBs (i.e. they follow the relationship  $L \propto T^4$ ). M82 X-1 might indeed be in a different state during these observations, instead. Mizuno et al. (2007) reported the cut-off in the spectrum of NGC 1313 X-1 in the power-law state of ULXs and Miyawaki et al. (2009) argued

**Table 3.** Models applied for the continuum intrinsic to M82 X-1 (i.e. without contribution from the galaxy). Intrinsic luminosities are calculated in the 0.5–10 keV and 2–20 keV energy range for *XMM-Newton* and *Suzaku* spectra, respectively.

Models	Parameters	Obs 1	Obs 2	Obs 3
Diskbb	$kT_{\text{in}}$ (keV)	$3.49 \pm 0.16$	$3.05 \pm 0.07$	$2.73 \pm 0.06$
	$\chi^2/\nu$	1.19	1.17	0.82
		(1589/1340)	(1636/1399)	(465/566)
	$L_X (\times 10^{40})$ (erg s $^{-1}$ )	$3.22 \pm 0.02$	$2.05 \pm 0.20$	$4.8 \pm 0.4$
CompTT	$kT_e$ (keV)	$2.08 \pm 0.02$	$2.21 \pm 0.02$	$2.26 \pm 0.02$
	$\tau$	$22.0 \pm 1.1$	$10.1 \pm 0.2$	$8.1 \pm 0.3$
	$\chi^2/\nu$	1.05	1.14	0.82
		(1400/1338)	(1589/1397)	(465/564)
	$L_X (\times 10^{40})$ (erg s $^{-1}$ )	$6.6 \pm 3.0$	$4.15 \pm 2.0$	$4.7 \pm 0.4$

that M82 X-1 was in the power-law state during Obs. 3, as well. Since there is barely any spectral evolution during these observations, we conclude that the source was in the power-law state during all the observations reported in this paper.

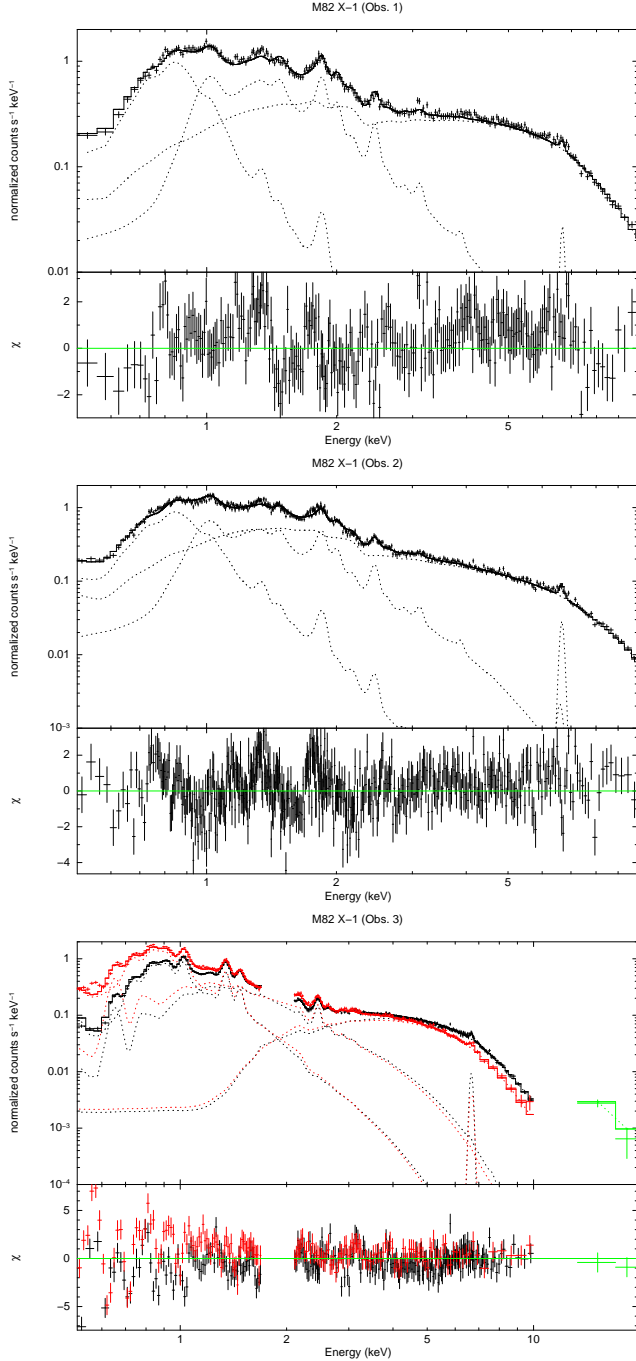
The X-ray spectra of M82 X-1 are reproduced very well by the compTT model (see results of spectral fits in Table 3), invoking a rather low electron temperature ( $kT_e = 2.0 - 2.3$  keV) and a large optical depth ( $\tau = 7 - 23$ ). The results of Obs. 3 agree with those obtained previously for M82 X-1. The statistics reported in this work for Obs. 3 is poor ( $\chi^2/\nu \geq 1.2$ ), since we considered the full 0.5–20 keV energy range in the fits of the *Suzaku* spectrum and below 2 keV there are unavoidable residuals most probably due to calibration effects (and/or) the limitation of our model to describe the diffuse emission from the galaxy. Since our goal is the study of the high-energy emission intrinsic to the source we will just consider the 2–20 keV energy range in the fits reported hereafter.

We can see from the results of fitting with both X-ray curved models that the description with a Comptonization model is a better description just for the spectrum of Obs. 1 (significant improvement by  $8\sigma$ ). We thus consider the Comptonization model a better description of the spectrum of Obs. 1. If luminosities from M82 X-1 are truly super-Eddington, then the mentioned parameters suggest that the cold-corona model proposed by Gladstone et al. (2009) is a possibility in the description of the spectra of ULXs, emitting in the so-called Very-High state. Nevertheless, this statement is just tentative and it is not required for the full data set analyzed in this paper. We will then consider both curved models (diskbb and compTT) as possible descriptions of the data and we will not discuss their validity any further.

#### 5 CONSTRAINTS OF AN EMISSION BROAD FE $K\alpha$ LINE IN THE *SUZAKU* SPECTRUM

The results of the previous Section with feasible models for the continuum leave some positive residuals in the 6–7 keV energy range in the *Suzaku*/XIS spectrum of Obs. 3 (see left panel of Figure 3). These residuals could not be accounted for by the addition of the narrow Fe line and indicate the likely presence of a broad Fe emission feature. To analyze this possibility further, we added a broad gaussian line to the best fit model (described in the previous Sections) of Obs. 3.

The addition of a gaussian centred at 6.4–6.97 keV in the best



**Figure 2.** *XMM-Newton* and *Suzaku* spectra of M82 X-1 (upper to lower) fitted with compTT model. Continuous curvature of the overall emission and diffuse emission from two hot plasmas ( $kT = 0.6$  keV and  $kT = 0.96$  keV) and galactic emission in the form of a narrow Fe line have been taken into account.

model describing the spectrum of Obs. 3 improves significantly the quality of the fit with any of the models used to describe the hard ( $\geq 2$  keV) X-ray spectra (improvement of  $\Delta\chi^2 = 13, 22$  for  $\nu = 3$  additional degrees of freedom for Disc and Comptonization models, respectively). This means a  $3.3 - 4.4\sigma$  detection, which means a F-test probability of  $< 0.1\%$  that the improvement occurs by chance with any of both models.

The line is broad ( $\sigma = 0.3 - 0.4$  keV) and the derived equivalent width (EW) of the line is of  $EW = 58_{-30}^{+18}, 59_{-27}^{+25}$  eV for the Disc

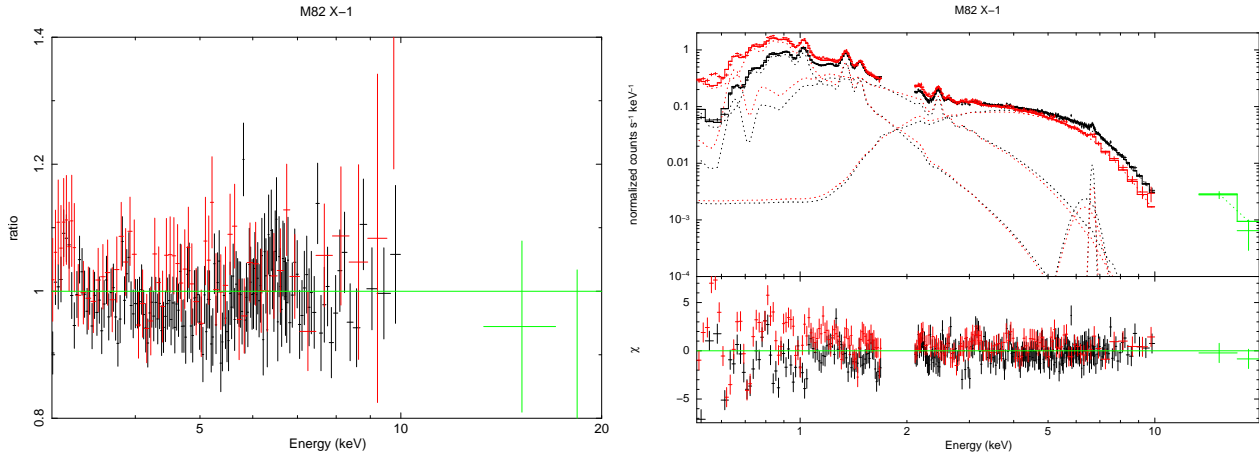
and the Comptonization models, respectively. We conclude that the value of the equivalent width of the line is significantly different from zero and that it is model-independent. Thus, we can consider the detection of the broad Fe line as a robust one, which does not depend upon the model considered for the continuum. In the right panel of Figure 3 we plot both the broad Fe line and the best description used for the underlying continuum.

### 5.1 Constraints on the spin of the Black Hole

As shown above the presence of a broad Fe line is significant in the *Suzaku* spectrum (Obs. 3). The Equivalent-Width is in the range 30–80 eV, in agreement with findings for some Active Galactic Nuclei, and it does not depend on the model applied for the continuum (Disc emission or Comptonization models). Accretion models predict that fluorescence lines broadened by relativistic effects could arise from reflection of X-ray emission onto the inner region of the accretion disc surrounding the black hole. In order to derive the inner disc radius and inclination we fitted the spectrum of Obs. 3 with a relativistic disc line profile calculated in a maximally spinning Kerr space-time (laor model in XSPEC; Laor 1991) but with the inner radius allowed to vary. We froze the emissivity index of the power-law emission and the outer radius to  $q = 3$  and  $R_{\text{out}} = 100 R_g$ , thus canonical values in BH-accreting systems. The inner disc radius was found to be  $R_{\text{in}} = 11_{-4}^{+9}, 10_{-4}^{+6} R_g$  (values corresponding to the Disc and Comptonization models, respectively, for the continuum). This value is comparable to or even larger than the innermost stable circular orbit of a non-rotating (Schwarzschild) BH (i.e.  $6 R_g$ ). The inner disc inclination was found to be very small, too ( $i = 15_{-15}^{+9}, 10_{-10}^{+13}^\circ$ ), thus implying a close face-on configuration. Adding this line supposed an improvement in the fit of  $\Delta\chi^2 = 15, 21$  for  $\nu = 4$  additional degrees of freedom for Disc and Comptonization models, respectively, thus very similar to the case of the inclusion of the broad gaussian.

## 6 DISCUSSION AND CONCLUSIONS

In the present work we have studied the best broad-band X-ray spectra of M82 X-1 currently available in X-rays from *XMM-Newton* and *Suzaku* satellites. With these high-quality data we have been able to disentangle emission from the diffuse plasma of the galaxy and intrinsic emission from the ULX. Our results imply that the X-ray diffuse emission is composed by a two-temperature thermal emission from a hot plasma in multi-phase state. Similar temperatures of the components ( $kT = 0.96 \pm 0.02, 0.60 \pm 0.02$  keV) have been found for the highest S/N *ASCA* spectra of nearby elliptical galaxies (Buote & Fabian 1998). The intrinsic spectrum of the source obtained with *Suzaku* is significantly curved and properly accounted by models with intrinsic curvature (either emission from the inner accretion disc or Comptonization from cold electrons in an optically thick corona), in agreement with previous studies. But the most important result of this paper is that the (very) high quality observation with *Suzaku* has allowed us to detect a significant broad Fe  $K\alpha$  line in the spectrum of this notorious ULX. Assuming that the line feature is solely coming from the ULX via disc fluorescence, and that the inner radius reaches the last stable orbit, the data rules out a rapidly spinning BH and favours a non-spinning Schwarzschild-BH. Previous studies (Feng & Kaaret 2010) have suggested that the BH in this ULX is rapidly rotating but the possibility of a non-spinning BH has not been rejected so far.



**Figure 3.** Ratio of the *Suzaku* spectrum with respect to the best model applied for the continuum (see text for details) (left) and spectrum with best fit model for the continuum plus the broad gaussian line component (right).

The obtained equivalent width (EW) is in the range 30–80 eV. This value for the EW (in Obs. 3) is notoriously lower than the tentative value previously reported (EW=0.26–0.43 keV; Strohmayer & Mushotzky 2003) for the spectrum of Obs. 1. With the application of our model for the diffuse emission and the continuum of the source, we do not detect any Fe line in the same dataset of their work (Obs. 1). We have found that in the *Suzaku* spectrum this line is broad and the EW is similar to typical values found for the broad Fe K line in a wide sample of AGN (de la Calle et al. 2010). The value we found for the EW is significantly smaller than those found in the typical cases of claimed relativistic lines (e.g.,  $\approx 300$  eV in MCG–6–30–15; Miniutti et al. 2007), for which an extremely fast rotating Kerr-BH has been claimed. Nevertheless, recent studies are setting much lower values (Noda et al. 2011) for the spin of this AGN, underlying in the fact that the continuum was poorly modelled.

In the previous work of analysis of the *Suzaku* spectrum by Miyawaki et al. (2009) the broad Fe line was described by the addition of several narrow lines. This hypothesis looks reasonable, since a similar complex has been clearly seen in our Galactic Centre (Koyama et al. 2007). Nevertheless, the presence of relativistically broad Fe lines seems to be common in all types of accreting compact objects (neutron stars, BHB, AGN) and evidence of their finding in ULXs would be very helpful in the understanding of the real physical processes accounting in these sources. Future longer X-ray observations will certainly provide further insights into the Fe complex and the presence of additional reflection features for this archetype of the ULX class.

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